FEKO™ Simulation of Radar Scattering from Objects in Low Earth Orbit for ISAR Imaging

Aaron Brandewie and Robert J. Burkholder
The Ohio State University ElectroScience Lab
Dept. of Electrical and Computer Engineering
Columbus, OH, U. S. A.
burkholder.1@osu.edu

***Abstract*—Objects in low earth orbit such as CubeSats and the International Space Station (ISS) move with constant velocity along a linear trajectory when viewed from a ground-based radar. The small change in attitude of the object as it flies overhead permits the generation of an inverse synthetic aperture radar (ISAR) image. In this paper, Altair's FEKO™ software is used to model the monostatic radar scattering from the ISS as a function of frequency and aspect angle. The computed data is used for generating a simulated ISAR image from a ground-based radar. The system design requirements for the radar are calculated from the radar equation.**

***Keywords*—electromagnetic scattering, inverse synthetic aperture radar, physical optics, radar imaging.**

I. INTRODUCTION

Quantification of the radar cross-section (RCS) of objects in low earth orbit (LEO) is needed for the design of ground-based radars that can detect, track and image these objects [1]. Keeping track of LEO objects is becoming especially challenging with the proliferation of CubeSats, not to mention the growing presence of space junk [2]. Historically, large dedicated ground-based radars have been used to track orbital objects, including the Goldstone radars, Haystack radars, and the USAF Space Surveillance Network [3]. These aging systems are in need of upgrade or replacement by new systems such as the IoSiS (Imaging of Satellites in Space) under development at the Microwaves and Radar Institute of German Aerospace Center [4], for example.

Objects in low earth orbit (LEO) follow linear trajectories with constant velocity with respect to a fixed ground-based radar staring up into space, as illustrated in Fig. 1. As the object flies overhead through the field of view of the radar, its attitude changes. This small rotation relative to the ground radar permits the generation of an inverse synthetic aperture radar (ISAR) image [5]. This is demonstrated here by simulation of the International Space Station (ISS) modeled in FEKO™ for a UHF radar system. Results for CubeSats will be presented at the conference for higher frequency bands.

Section II describes the FEKO™ model of the ISS and shows the simulated image of the ISS generated from FEKO™ data. Section III investigates the requirements for the ground-based radar using the radar equation. Section IV discusses conclusions and additional work presented at the conference.

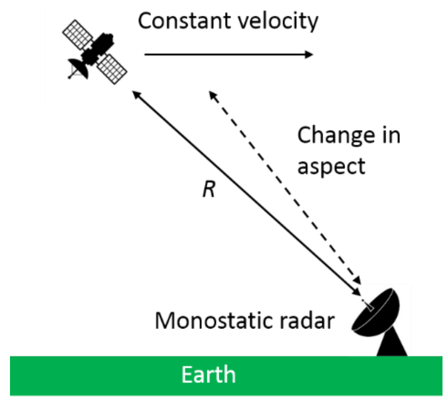

Fig. 1. Ground-based radar tracking a LEO object flying overhead. The change in aspect allows an ISAR image to be generated.

II. FEKO™ MODEL OF THE ISS

Fig. 2 (a) shows a graphic of the ISS and Fig. 2 (b) shows the FEKO model used here. There have been many variations and modules associated with the ISS over the years, so a basic configuration was chosen to capture the dominant scattering features. The overall dimensions are roughly 108 m x 73 m.

Due to its large size, a UHF radar should be able to easily track and image the ISS. A frequency band of 500-560 MHz with 121 points is chosen for the simulations. Monostatic scattering data is generated over azimuth angles 60° to 70° with 41 points. The downrange resolution is 2.5 m and the cross-range resolution is 1.6 m for the 10° aspect range. The elevation angle is 10° with respect to the *x-y* plane. The scattered field is computed using large element physical optics with full ray tracing in the FEKO solver. The total computation time was about 1 minute on a laptop computer.

Fig. 2 (c) shows the ISAR image of the ISS computed using back-projection of the backscatter data with a Hamming window over both frequency and angle [5]. The image is projected into the *x-y* plane from the 10° slant plane. The dominant features are clear in the image, although the large flat surfaces of the solar panels are not seen because the aspect is far from broadside. The average RCS is around 10 dBsm over this range of aspects.

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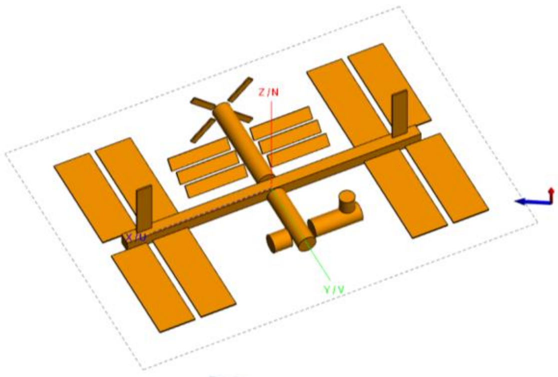
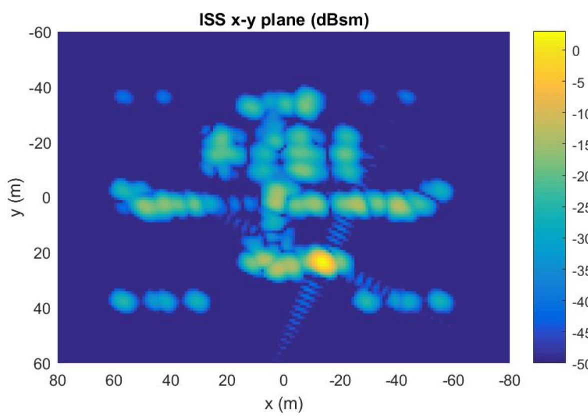
(a) www.gettyimages.com



(b) FEKO™ model



(c) ISAR image

Fig. 2. International Space Station (ISS). (a) ISS in orbit. (b) FEKO model. (c) UHF ISAR image projected in the *x*-*y* plane seen from an elevation slant plane of 10° (dBsm). A 10° azimuth window is used to generate the image.

III. Radar System Requirements

To understand the trade-offs involved with the design of a ground-based radar for tracking LEO objects, we begin with the monostatic radar equation [1]. Neglecting atmospheric attenuation, the received power at a single frequency is given by,

$$P_r = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 R^4}, \tag{1}$$

where P_t is the transmitted power, G is the gain of the antenna, λ is the wavelength, σ is the RCS, and R is the distance. The ISS orbits at approximately 400 km, and the RCS is conservatively 10 dBsm away from broadside according to the FEKO simulation. The noise power of the receiver at room temperature for our 60 MHz bandwidth is -126 dB. Integrating (1) over the entire bandwidth, assuming a 1 second total integration time and a signal-to-noise ratio of at least 10 dB, we require $P_r B$ > -116 dB where B is the bandwidth. Using (1) we find that $P_t G^2$ > 58 dB. This is achievable with a 20 dB antenna and 63 W average transmitted power. A UHF antenna with 20 dB gain can be easily constructed using an array of five 6 dB antennas.

IV. Conclusions

It has been demonstrated through FEKO simulation that ISAR imaging of LEO objects is possible using a ground-based radar. Specifically, the ISS was simulated for a UHF radar, and the radar equation was invoked to calculate the ground-based antenna and power requirements. The imaging is possible by observing the LEO object for 10 seconds, providing a 10° change in aspect. It was also shown that a radar with a 10% duty cycle and average transmitted power of 63 W, combined with a 20 dB antenna, could track and image the ISS. This is possible because LEO objects travel along a predictable path with known velocity, thus allowing a relatively long coherent processing interval.

References

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